Fermi National Accelerator Laboratory

FN-274
2600.000

(Submitted to the International Colloquium on "Neutrino Physics at High Energy," Paris, France, March 18-21, 1975)

15-FOOT BUBBLE CHAMBER NEUTRINO PHYSICS

F. R. Huson

April 1975

Operated by Universities Research Association Inc. under contract with the Energy Research and Development Administration

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This paper is a progress report on neutrino physics in the 15-foot bubble chamber and not a paper with final results. The neutrino hydrogen data are from the Fermilab-University of Michigan Collaboration and the external muon identifier (EMI) data from the Hawaii-Lawrence Berkeley Laboratory Collaboration. The near future neutrino area program is also presented. Since this is the first paper to present 15-foot results it is a pleasure to acknowledge the following people: J. Sanford, head of experimental facilities during construction; W. B. Fowler, head of the bubble-chamber program during construction; F. R. Huson, responsible for design and construction of the 15-foot; T. Toohig, head of neutrino area during beam construction; and F. Nezrick, project leader for horn construction and neutrino beam monitoring. G. Mulholland and W. Smart worked on the construction of the chamber and initial operation. G. Mulholland is now the 15-foot group leader.

Bubble Chamber

The bubble chamber is shown in Fig. 1. There are three cameras that simultaneously cover 26 cubic meters of liquid. With a fiducial volume defined by the field of view of the cameras on top, by 5 centimeters from the wall in front and by 35 centimeters of potential length downstream this is reduced to 21 cubic meters. Figures 2, 3, and 4 show neutrino events in the chamber.

Last year there were two runs for the chamber, one in August and another in October-November. During a total of 12 weeks, 177,000 pictures were taken averaging 15,000 per week. A total of 108,000 pictures were taken for three different neutrino experiments: Fermilab-University of Michigan, 68,000 pictures ν hydrogen; Hawaii-Lawrence Berkeley Laboratory, 14,000 pictures ν hydrogen; Argonne National Laboratory-Carnegie Mellon University, 26,000 pictures of $\bar{\nu}$ hydrogen.

The magnetic field was about 21 kilogauss for the experiments. The setting error in the chamber is about 300 microns. Figures 5 and 6 show geometry FRMS values. Figure 7 shows that $\Delta p/p$ is about 0.6% for a 2 meter track up to 10 GeV/c and 4% for a 100 GeV/c 2 meter track. We believe the relative small setting error this early in the life of the chamber is principally due to "standard" 108° lenses, careful measurement of more than 100 fiducials in the chamber and careful placement of cooling loops to avoid thermal currents in the chamber.

Beam

During the experiment the beam was continuously monitored with the aid of a PDP-11. The position of the proton beam on the target and its intensity, the position of muons in the shield for neutrino beam centering and the horn voltage and wave form were the principal parameters recorded. During the experiment one horn was used due to problems with the transmission line between the two horns. Figure 8 gives the calculated neutrino flux using the Hagedorn-Ranft production model.

The accelerator delivered between 0.3 and 1.3×10^{13} protons per pulse during the experiment. The total number of protons for the experiment has not yet been computed.

Neutrino Hydrogen Experiment (E45)

Of the 68,000 pictures 45,000 are good 3 view pictures; 15,000 are 3 view with bad stereo cameras; 8,000 are 2 view and test pictures. The data in this paper are from 26,000 pictures. They are raw data, remeasurements and various necessary corrections have not been made. When we cut on visible energy at 10 GeV/c including gammas and vees we have 274 events.

The scan rules used are as follows:

(i) Vertex visible in 3 views
(ii) $\geq$ 3 tracks
(iii) If 3 tracks
  (a) 1 track > ~1 GeV/c
  (b) 1 track > ~1 GeV/c not in backward 140° cone. This cuts most elastic scattering simulating neutrino events.
(iv) Record all relevant information.

The scanning is done on tables with 25× and 70× magnification (70 is lifesize). Most of the measurements are done on a table with 70× magnification and 2 micron accuracy.

The CERN Hydra system of geometry and kinematics is used. At present there is still some trouble with tracks that come toward the optics and are very far from a circle on the film. The pass rate of events in geometry is approximately 90%.

Figure 9 shows some probability distributions for vee fits. The vees were obtained from hadron film of 250 GeV/c π^- in the chamber. The top set of graphs is a 3 constraint fit containing pointing information, the middle set of graphs is the 1 constraint fit not including pointing information for the events that have a 3 constraint fit also. The bottom set of graphs are 1 constraint fits only; the 3 constraint fit did not converge. It is believed that these events do not point to the measured primary vertex. This is being verified now.

Figure 10 represents the method used to separate gammas and vees. Gammas are fit to the hypothesis:

$$\gamma + p \rightarrow p + e^{+} + e^{-}.$$

The first figure shows the recoil proton momentum distribution and the second the transverse momentum of the electron to the gamma direction. Verification of the event shows that good separation of gammas and vees can be made with the cuts indicated on the figure.

Figure 11 shows the mass squared distribution for K_S^o from the hadron film. The mass is wrong due to the magnetic field. After this measurement we recalled that 1 of the 44 pancakes of the magnet was not installed because the superconductor was bad. This is now being put into the magnetic field program.

The conclusion from the above data is that we are beginning to understand the chamber parameters reasonably well -- that there are not large distortions in the chamber and we can begin to believe the data obtained from the geometry-kinematics programs.

Figure 12 shows the visible energy distribution for the 274 raw events. We have cut events with less than 10 GeV/c visible momentum. The curves in the figure were obtained in the following manner: the neutrino energy spectrum curve of Fig. 8 was multiplied by E, assuming cross section is proportional to energy, and the energy scale reduced by a factor of 1/1.3 to approximate missing neutrals. To approximate neutral currents the energy scale was reduced by another factor of 2. The normalization was made by assuming the neutral currents for $E_{visible} > 10$ GeV/c was 10% of the charged currents and the integrated total equaled the number of events. Clearly this is a rough approximation, but does represent the make-up of the distribution.

Figure 13 shows the multiplicity for various visible energy bands. Mean multiplicities are not given since these are preliminary data and have not been corrected for Dalitz pairs, close gammas and vees etc.

Approximately 1/3 of the events have either gammas and/or vees. Approximately 1/4 of these are vees.

EMI

To complete the picture of the bubble-chamber program I shall present the status of the Hawaii-Lawrence Berkeley Laboratory EMI. Figure 14 shows the placement of 21 - 1 × 1 meter squared (there are now 24) proportional wire chambers. Figure 15 shows the hadron absorber made up of chamber walls, magnet material and zinc. Using a Monte-Carlo with standard neutrino production properties they predict the absorption length distributions given in Figs. 16 and 17 for muons and hadrons. Figure 18 gives the resolution of the wire chambers relative to the bubble chamber. If a track remains within this resolution (~1 cm) it is defined to be a muon.

Multiple scattering is included in definition. Figure 19 gives the geometrical acceptance for muon detection. By making the additional assumptions that a hadron is identified by:

(i) $p \leq 400$ MeV/c
(ii) interaction in the chamber
(iii) decays in the chamber
(iv) does not reach the EMI when predicted. It should if muon.
(v) stops in the chamber.

The efficiency for neutral current detection can be calculated. Figure 20 shows these efficiencies for chamber plus EMI and chamber alone as a function of x and y. The average detection efficiency for EMI plus chamber for neutral currents is about 75%.

Figure 21 shows the results for 22 events studied by the Hawaii-Lawrence Berkeley Laboratory group. Nine events have $E_{visible}$ greater than 10 GeV/c. Of these 6 had an "identified" muon, 2 had all hadrons, and 1 was undetermined.

Near Future Neutrino Area Program

First of all there is a lot of data already taken that should give many results within the next few months. The 15-foot bubble chamber is just beginning another run. It is planned to operate the chamber with 20% neon for Experiment 28 (Wisconsin-Hawaii-Lawrence Berkeley Laboratory). The chamber will have the fiberglass piston and should operate at full field (30 kG). Both horns will be installed. If the chamber and beam operate correctly, Fermilab will also try to take antineutrino pictures for E172 and/or E180. This program may continue until June 15 with a 3 week shutdown in April.

At that time the narrow band neutrino beam will probably be installed for Experiments 21 and 254.

ANL-C.M.U. $\bar{\nu}$ Experiment

Figure 22 presents the results from the Argonne National Laboratory-Carnegie-Mellon University antineutrino hydrogen experiment in the 15-foot bubble chamber.

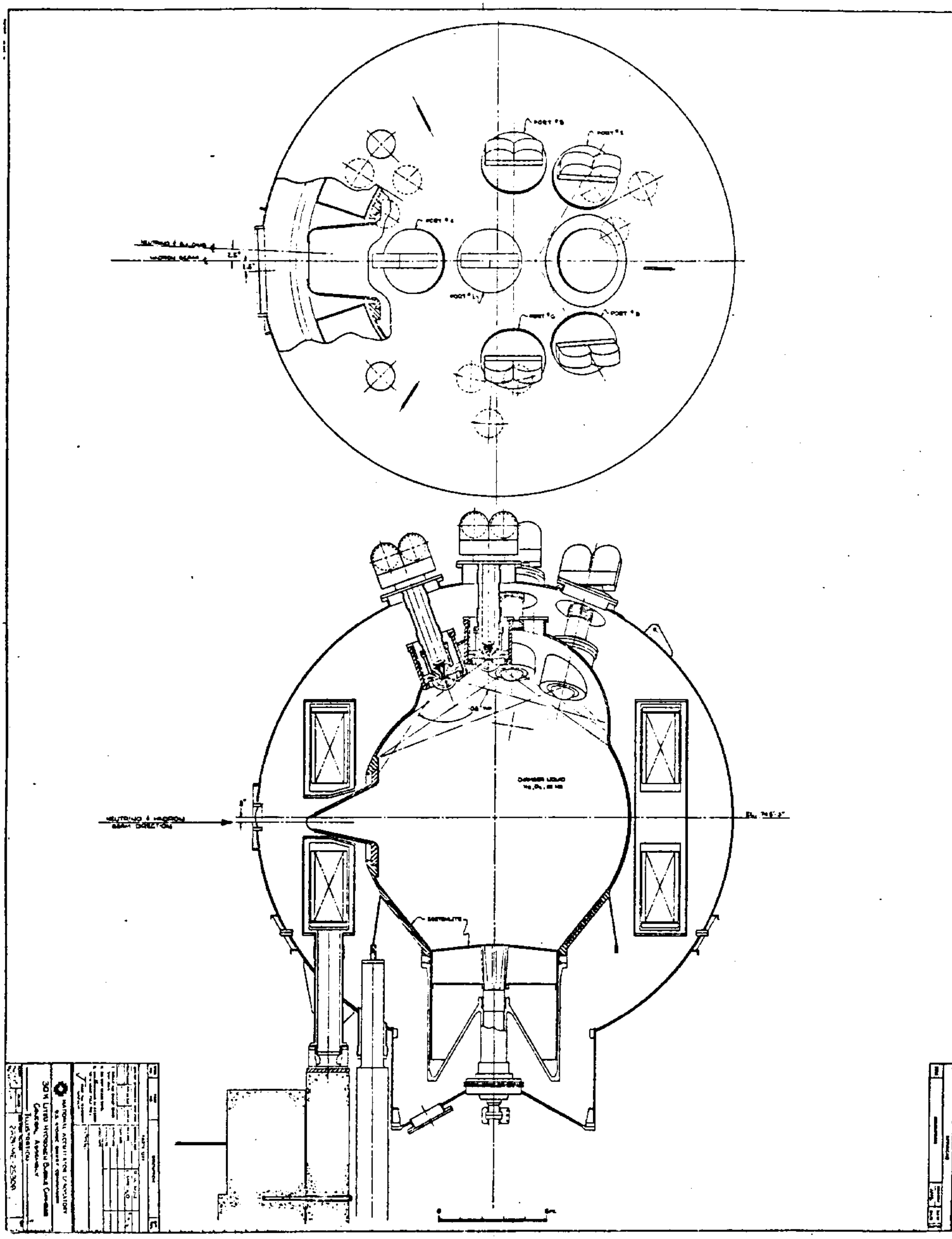


Fig. 1

Fig. 2

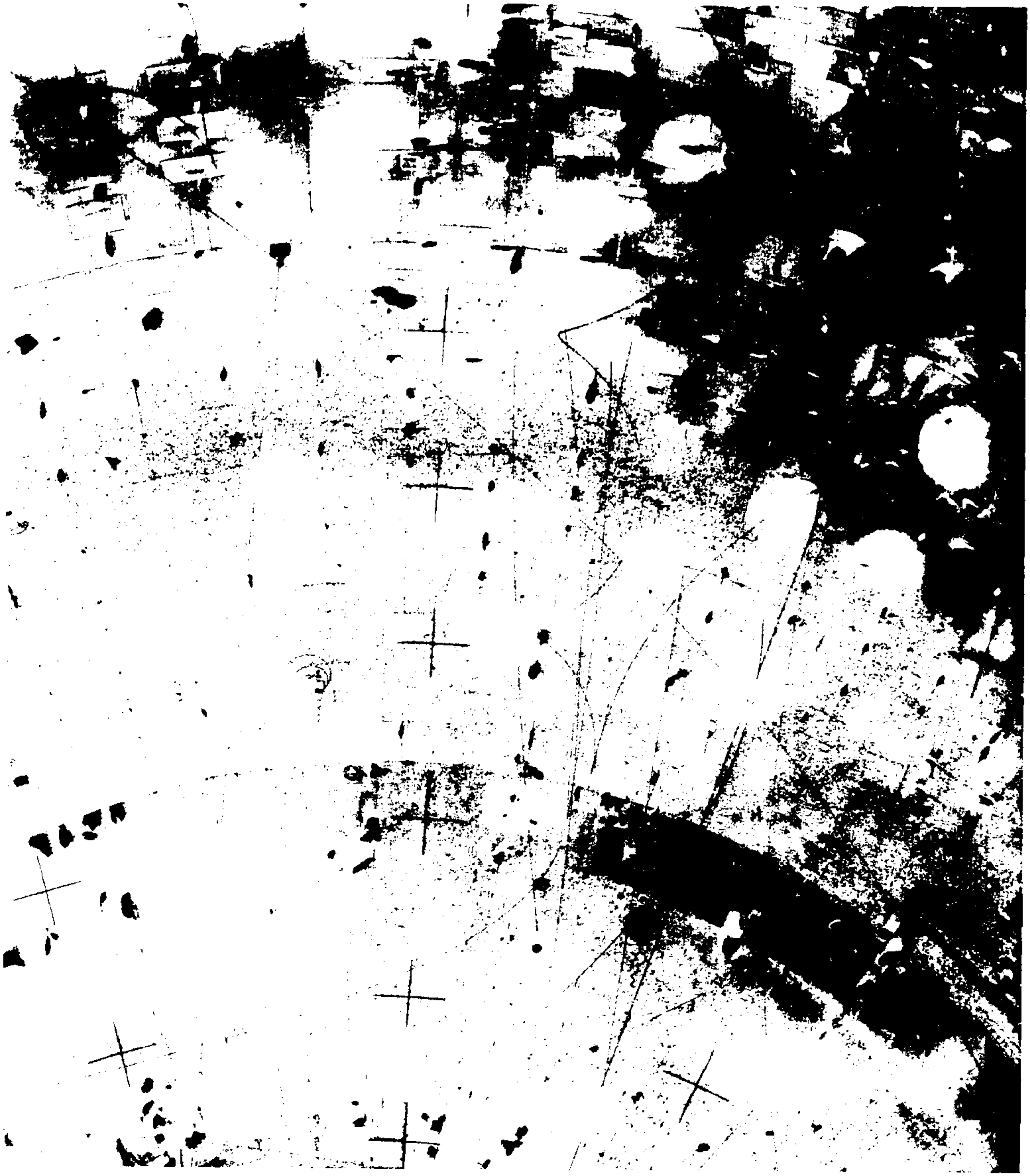


Fig. 3

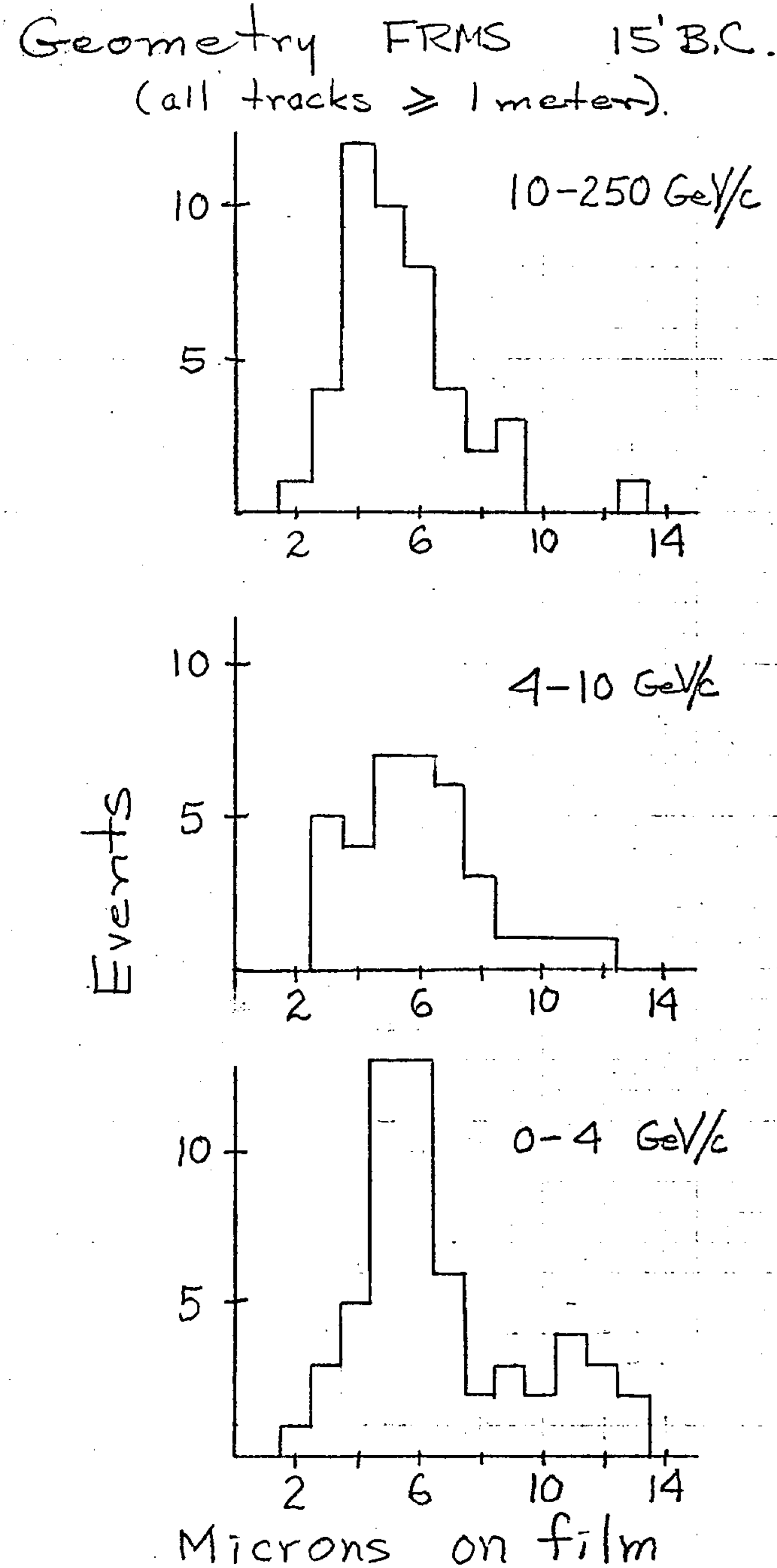
Fig. 4

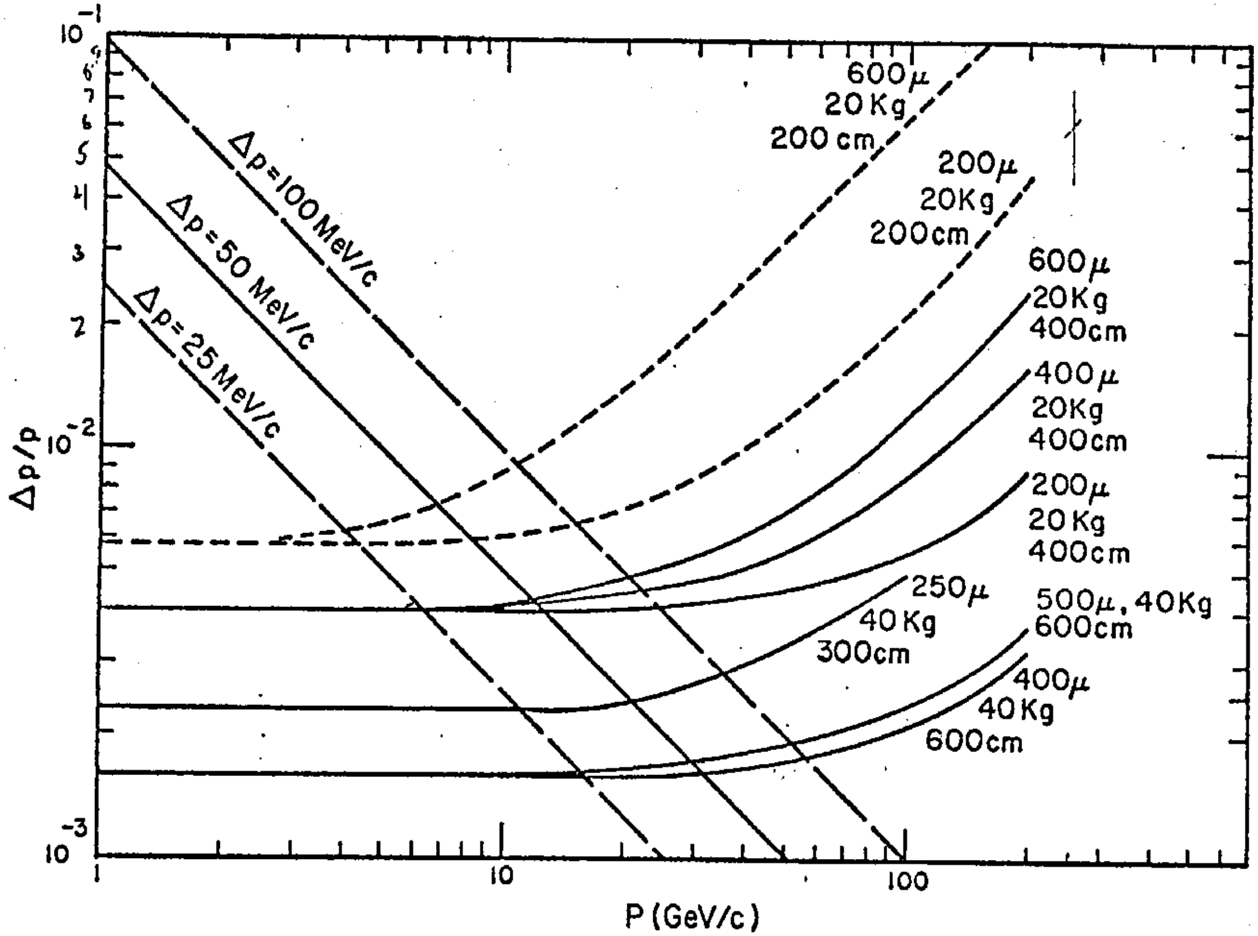
```
MASTER TESTS       1
XLOC   430   431   432   433   434   435   436   437   438   439   440   4
WLOC     Ø     Ø     Ø     Ø     Ø     Ø     Ø     Ø     Ø     Ø     Ø
TEST     Ø     Ø     Ø     Ø     Ø     Ø     Ø     Ø     Ø     Ø     Ø


  324     3
  315     X
  306     X
  297     X
  288     X
  279     X                        2665 tracks.
  27Ø     X
  261     X6
  252     XX
  243     XX
  234     XX
  225     XX
  216     XX
  2Ø7     XX7
  198     XXX
  189     XXX
  18Ø     XXX
  171     XXX
  162     XXX
  153     XXX
  144     XXX
  135     XXX
  126     XXX
  117     XXX
  1Ø8    5XXX8
   99    XXXXX5
   9Ø    XXXXXX
   81    XXXXXX
   72    XXXXXX5
   63    XXXXXXX
   54    XXXXXXX5
   45    XXXXXXXX8
   36    XXXXXXXXXX
   27    XXXXXXXXXX66
   18    XXXXXXXXXXXX26    2
    9   1XXXXXXXXXXXXXXX566X433245 6546113111 11    111    1 11
 SIGN
         13221
 CON-    Ø15ØØ965432211    1
 TENT   14885758Ø46441556614332245 6546113111 11    111    1 11
        .Ø
         Ø   10%   20%   30%   40%

 CHAN                1          2          3          4          5
        1234567890123456789012345678901234567890123456789012345
```

Fig. 5


Geometry FRMS 15' B.C.
(all tracks ≥ 1 meter).
10-250 GeV/c
4-10 GeV/c
0-4 GeV/c
Events
Microns on film
10
5
2
6
10
14
Fig. 6



Effect of varying the setting error on the total momentum error, for the same four bubble chambers.

Fig. 7

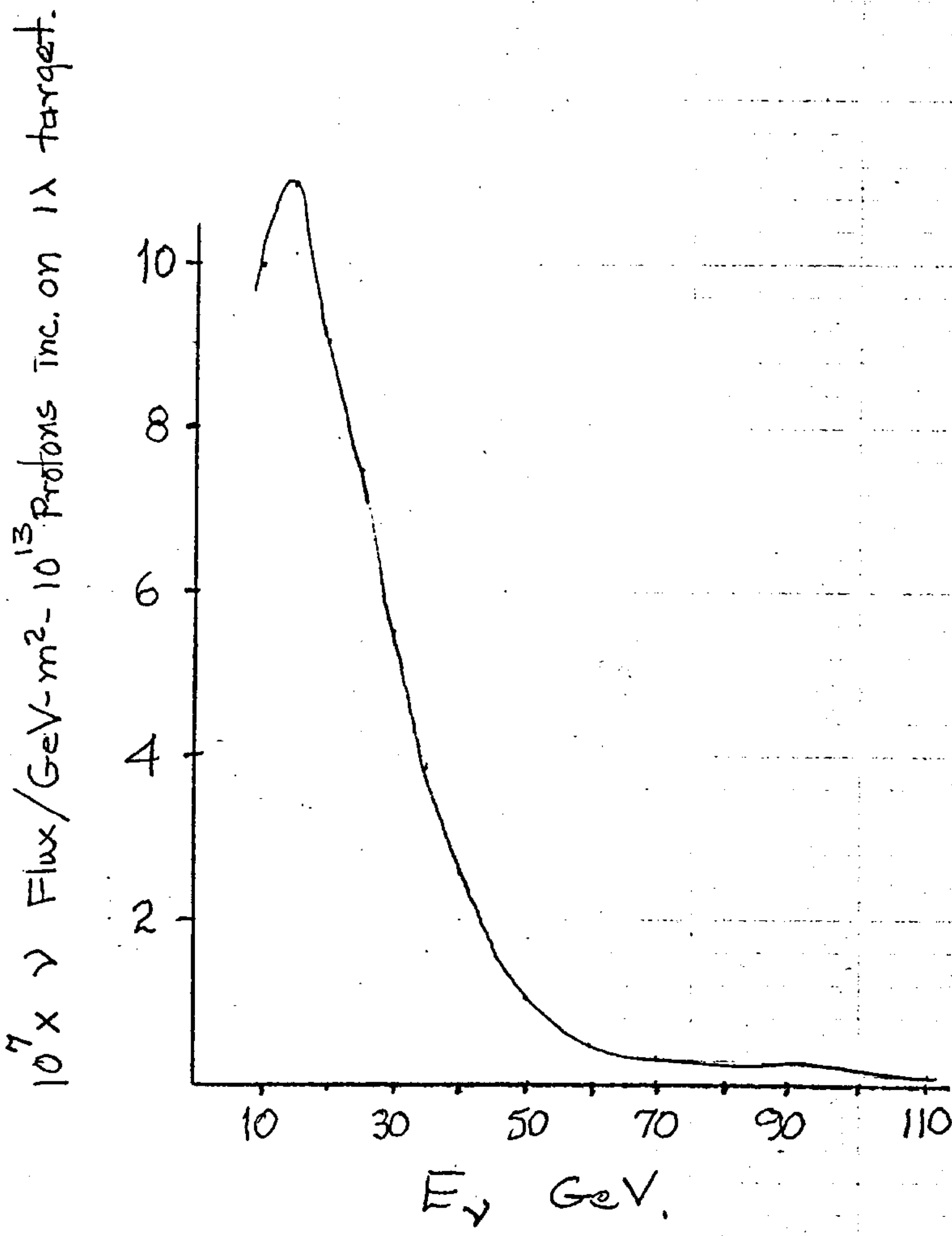
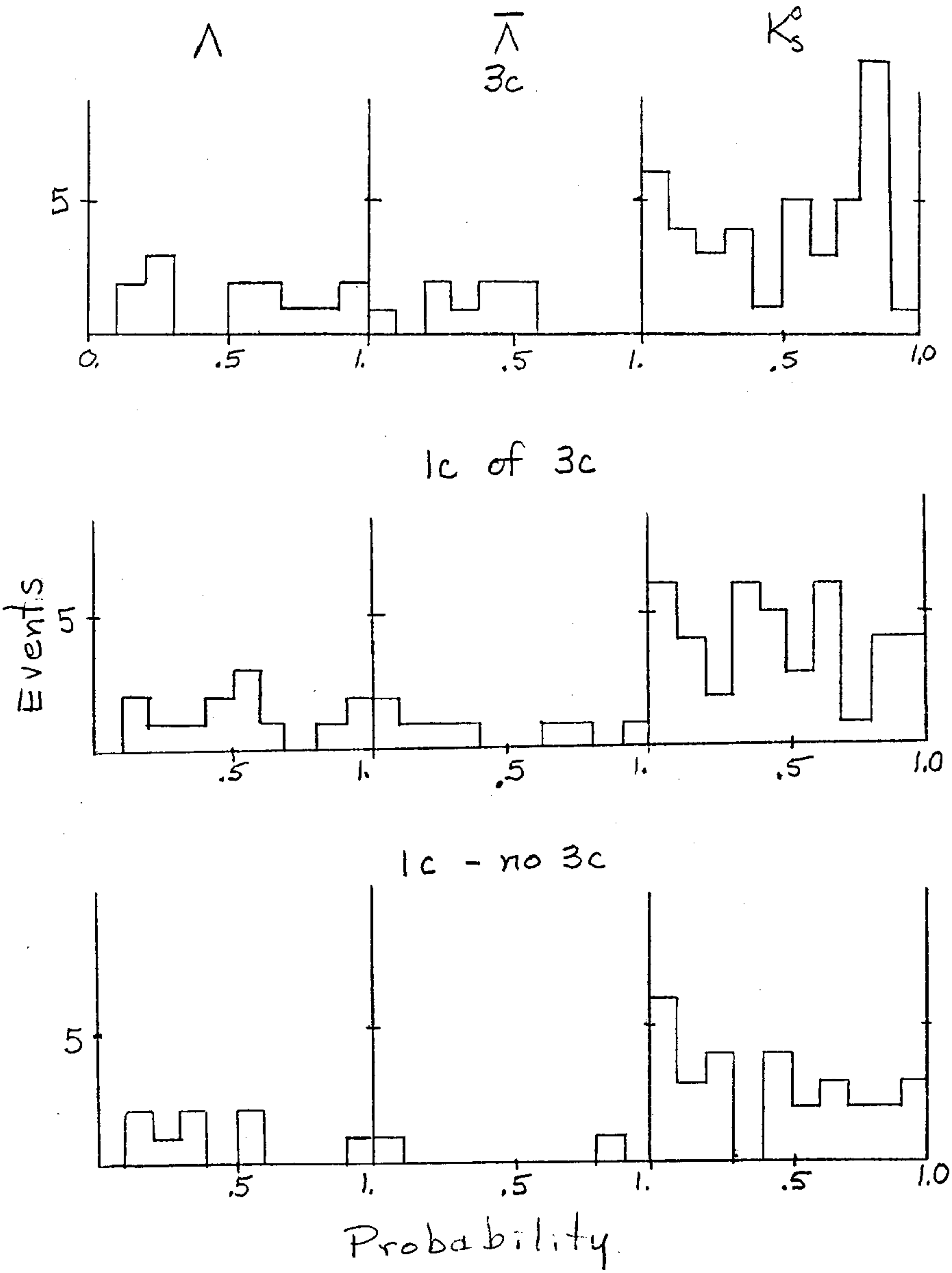
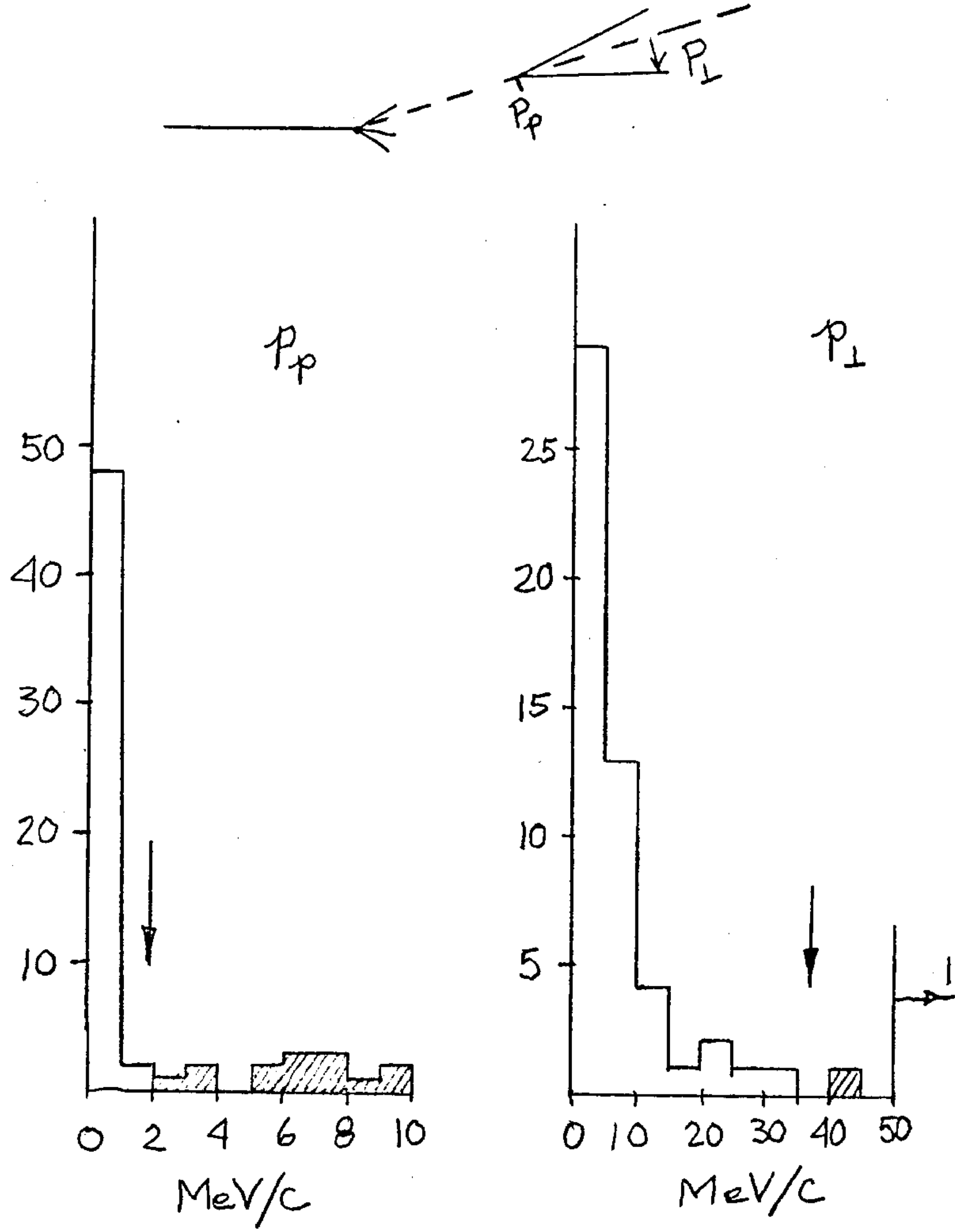

$10^7 \times \nu$ Flux/GeV-m²-10^{13} Protons Inc. on 1λ target.
10
8
6
4
2
10
30
50
70
90
110
E_ν GeV.

Fig. 8



Λ
$\bar{\Lambda}$
K_s^0
3c
5
0.
.5
1.
.5
1.
.5
1.0
1c of 3c
Events
5
.5
1.
.5
1.
.5
1.0
1c - no 3c
5
.5
1.
.5
1.
.5
1.0
Probability

Fig. 9



$P_\perp$
p_p
p_p
$p_\perp$
50
40
30
20
10
0
2
4
6
8
10
MeV/c
25
20
15
10
5
13
0
10
20
30
40
50
MeV/c

Fig. 10

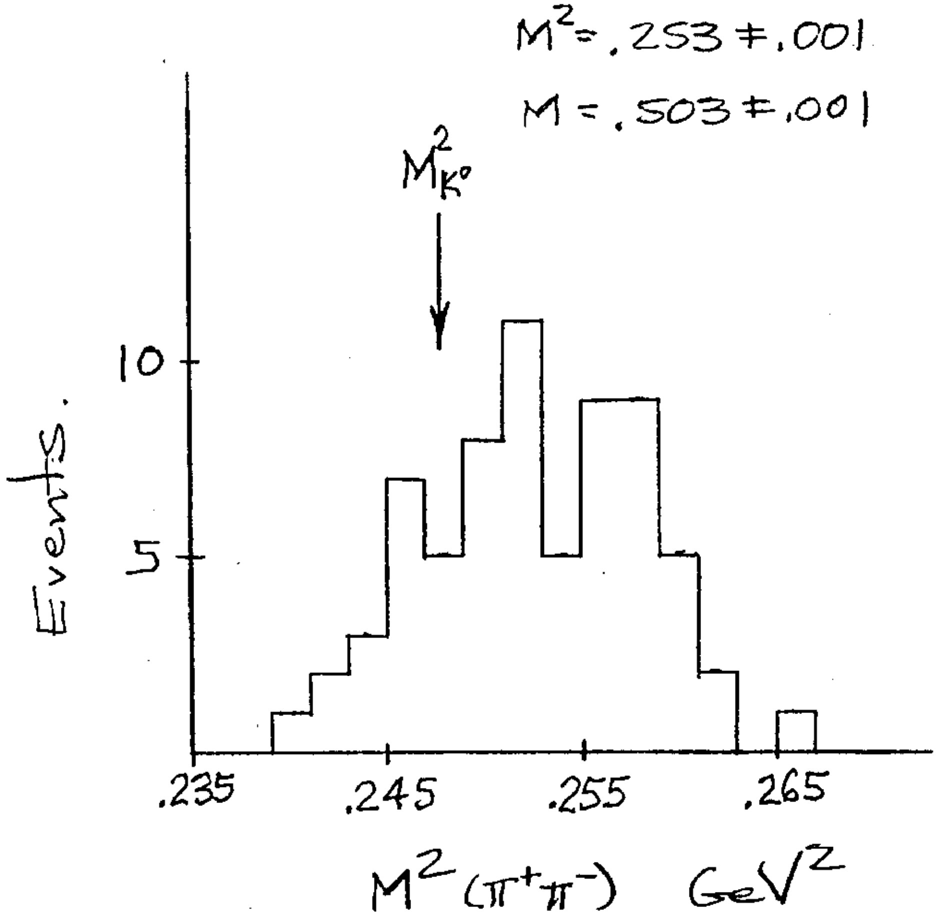

$M^2 = .253 \mp .001$
$M = .503 \mp .001$
$M^2_{K^0}$
10
5
Events.
.235
.245
.255
.265
$M^2(\pi^+\pi^-)$ GeV^2

Fig. 11

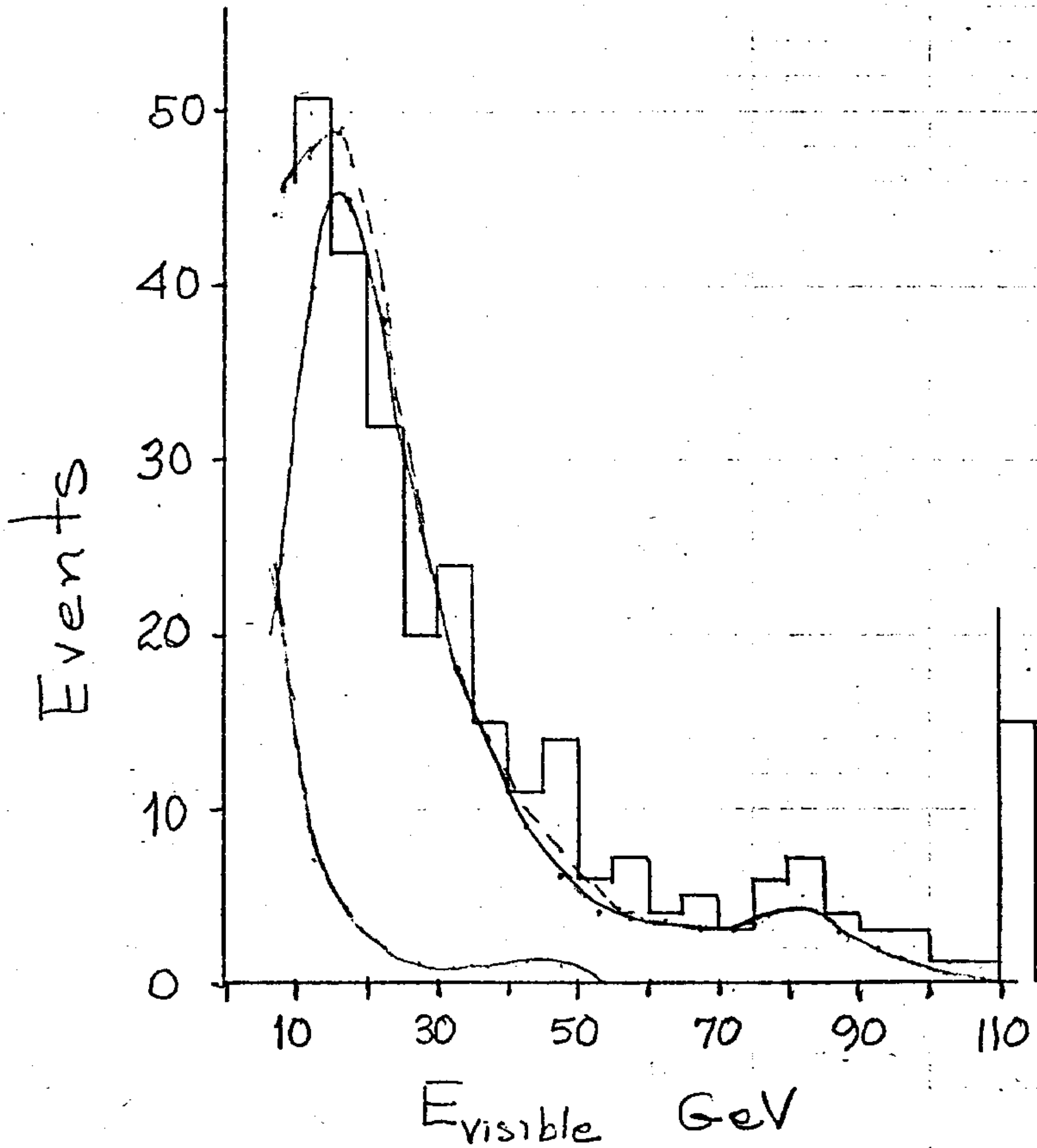


Fig. 12

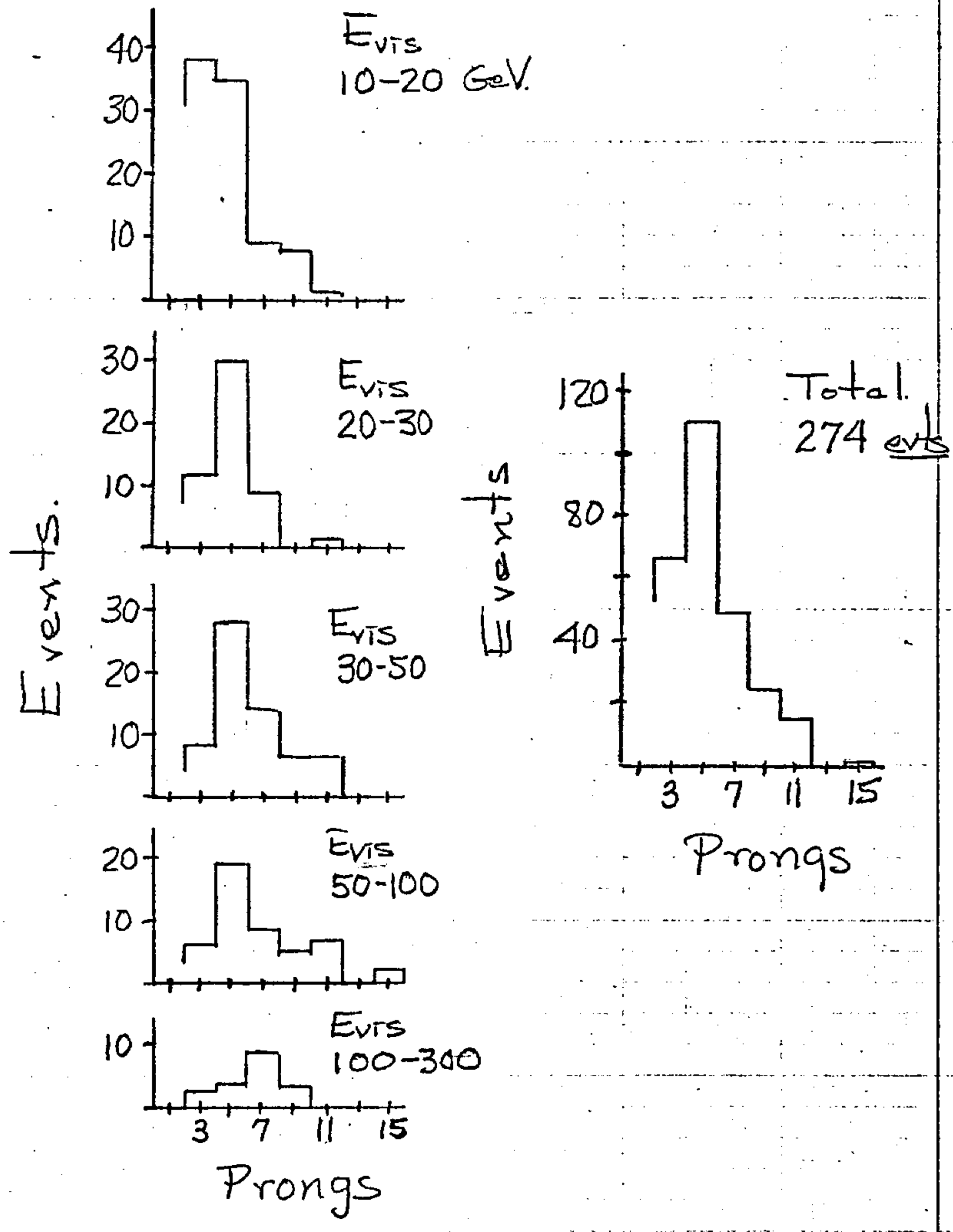
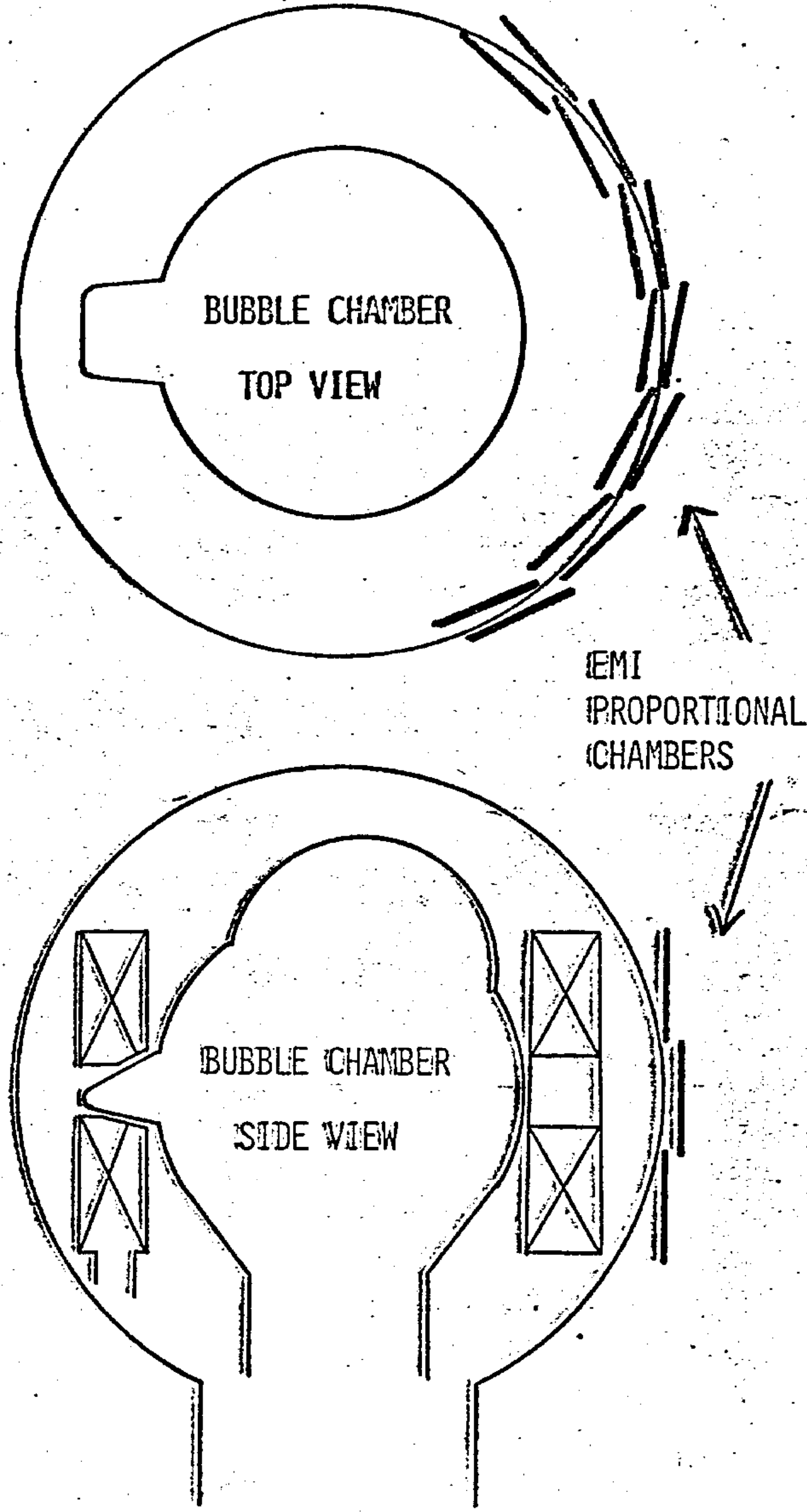

Evis
10-20 GeV.
Evis
20-30
Evis
30-50
Evis
50-100
Evis
100-300
Events.
Prongs
Total
274 evts
Events
Prongs

Fig. 13



GEOMETRY OF THE EXTERNAL MUON IDENTIFIER

Fig. 14

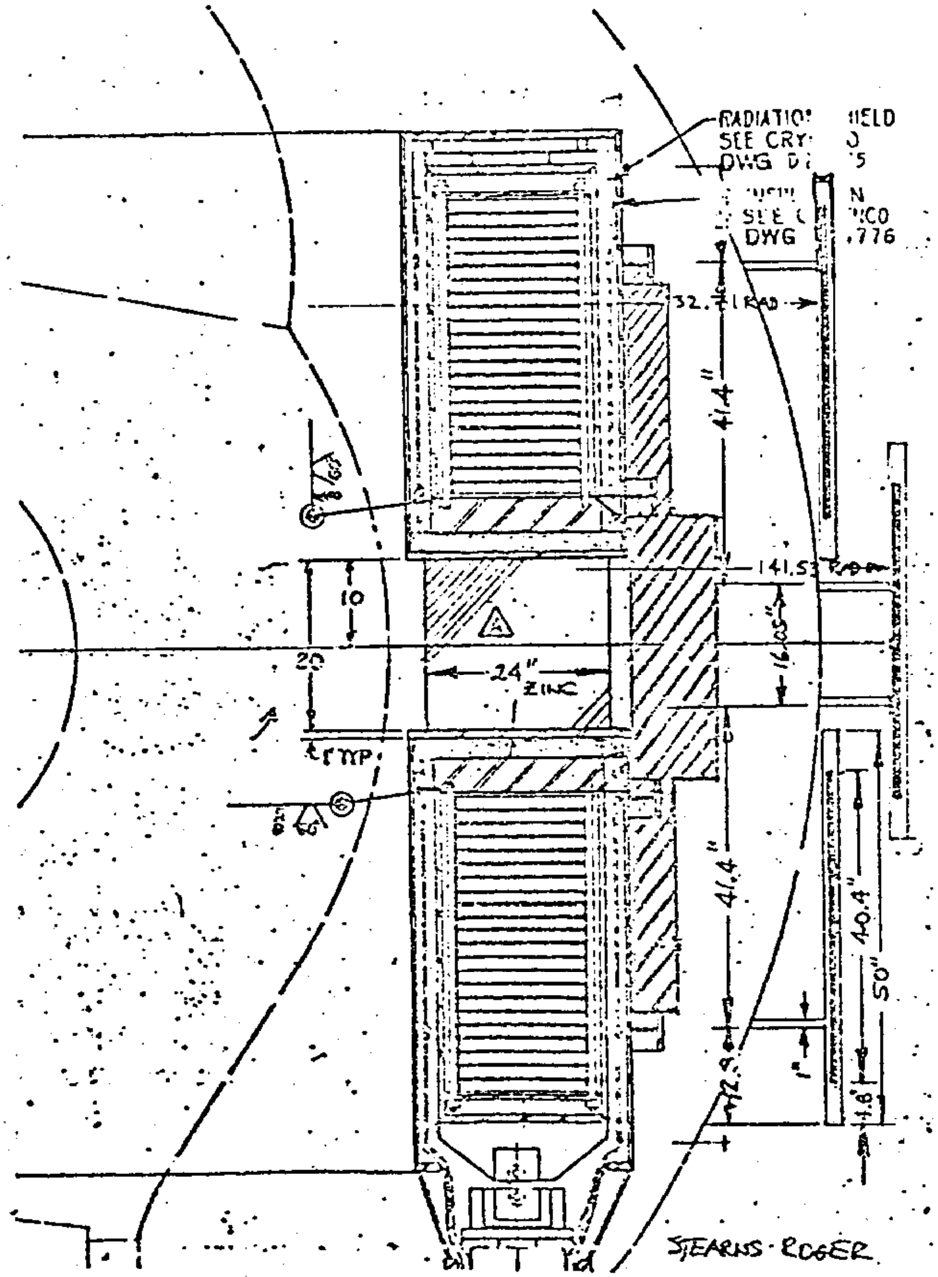
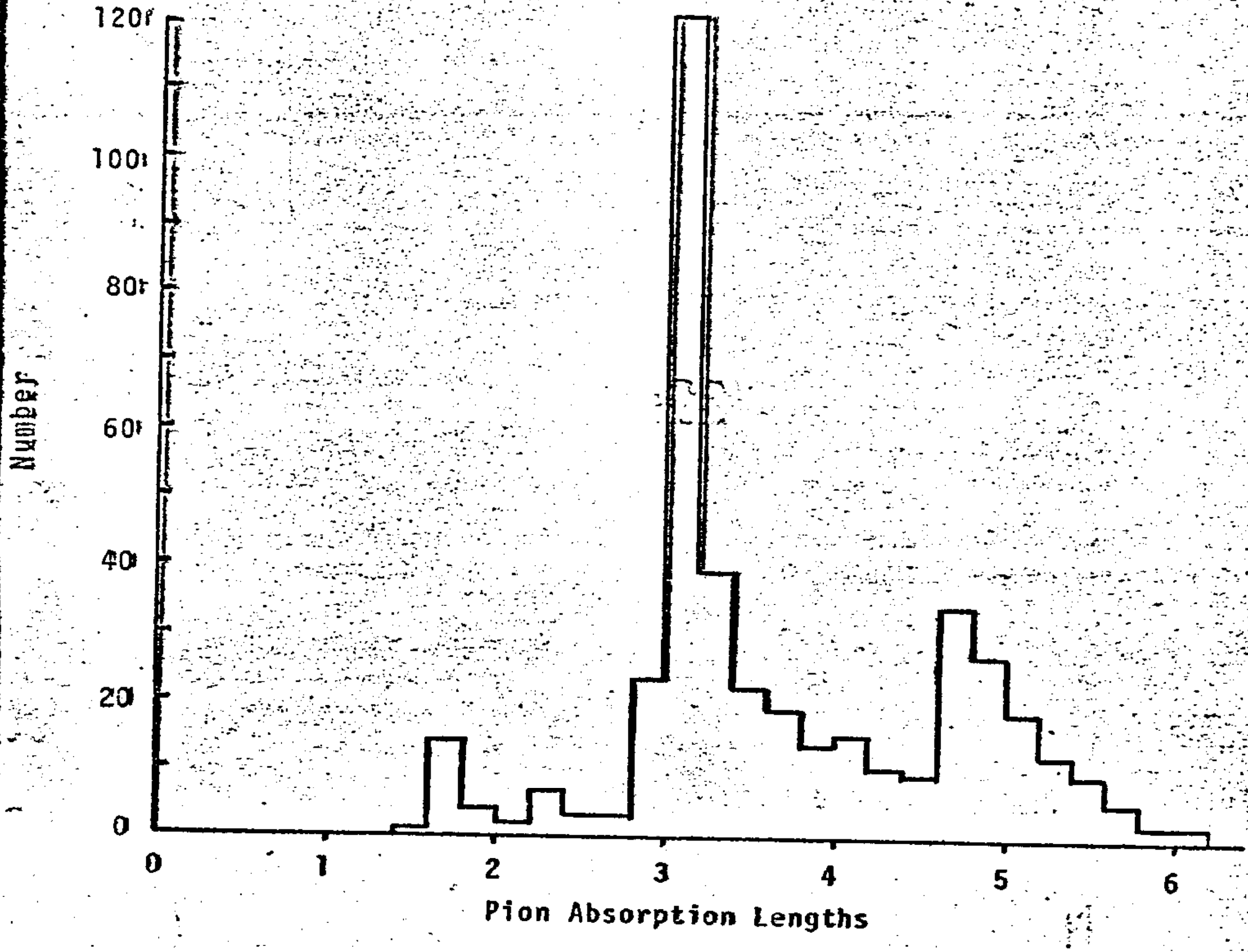
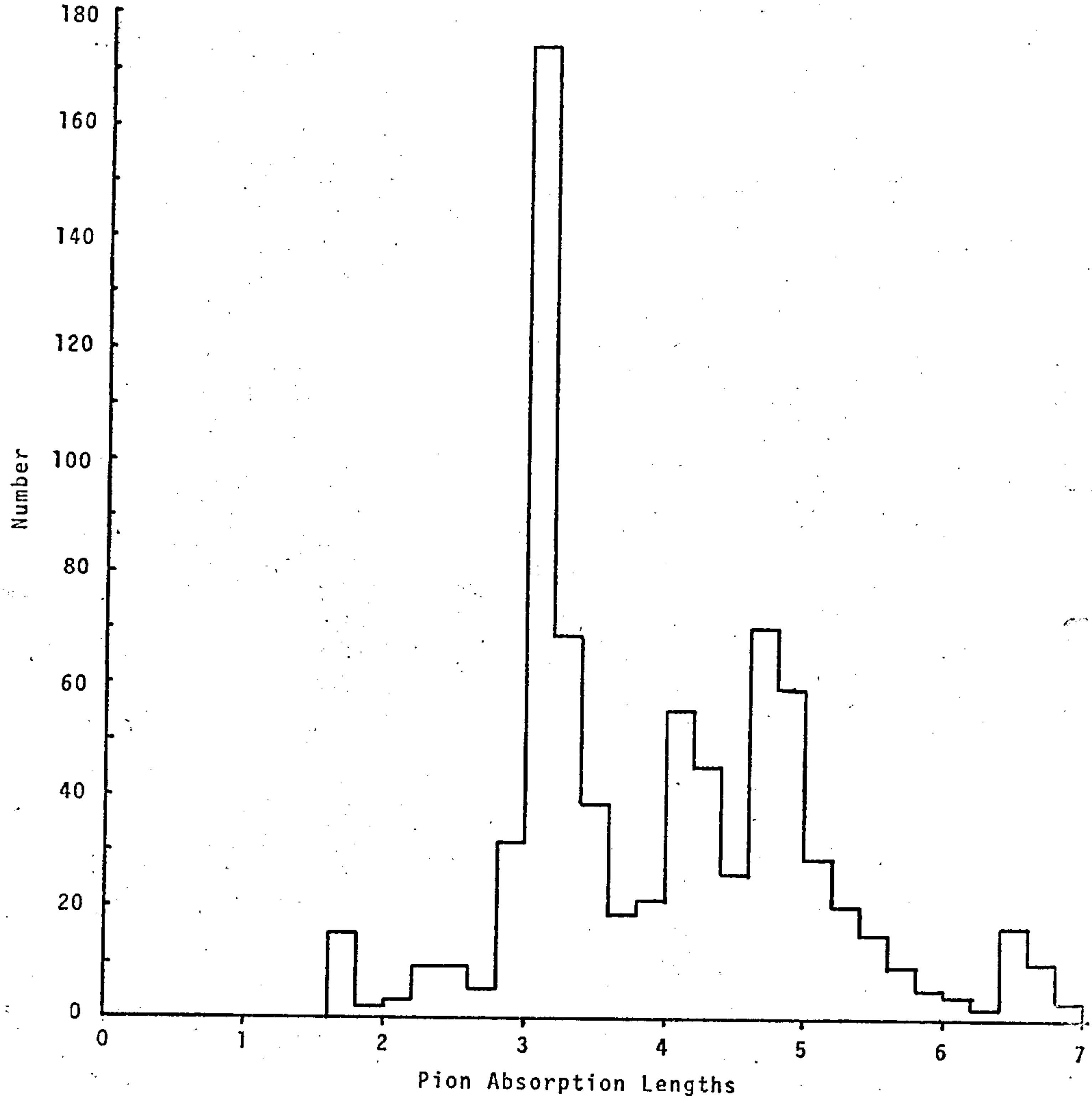


Fig. 15



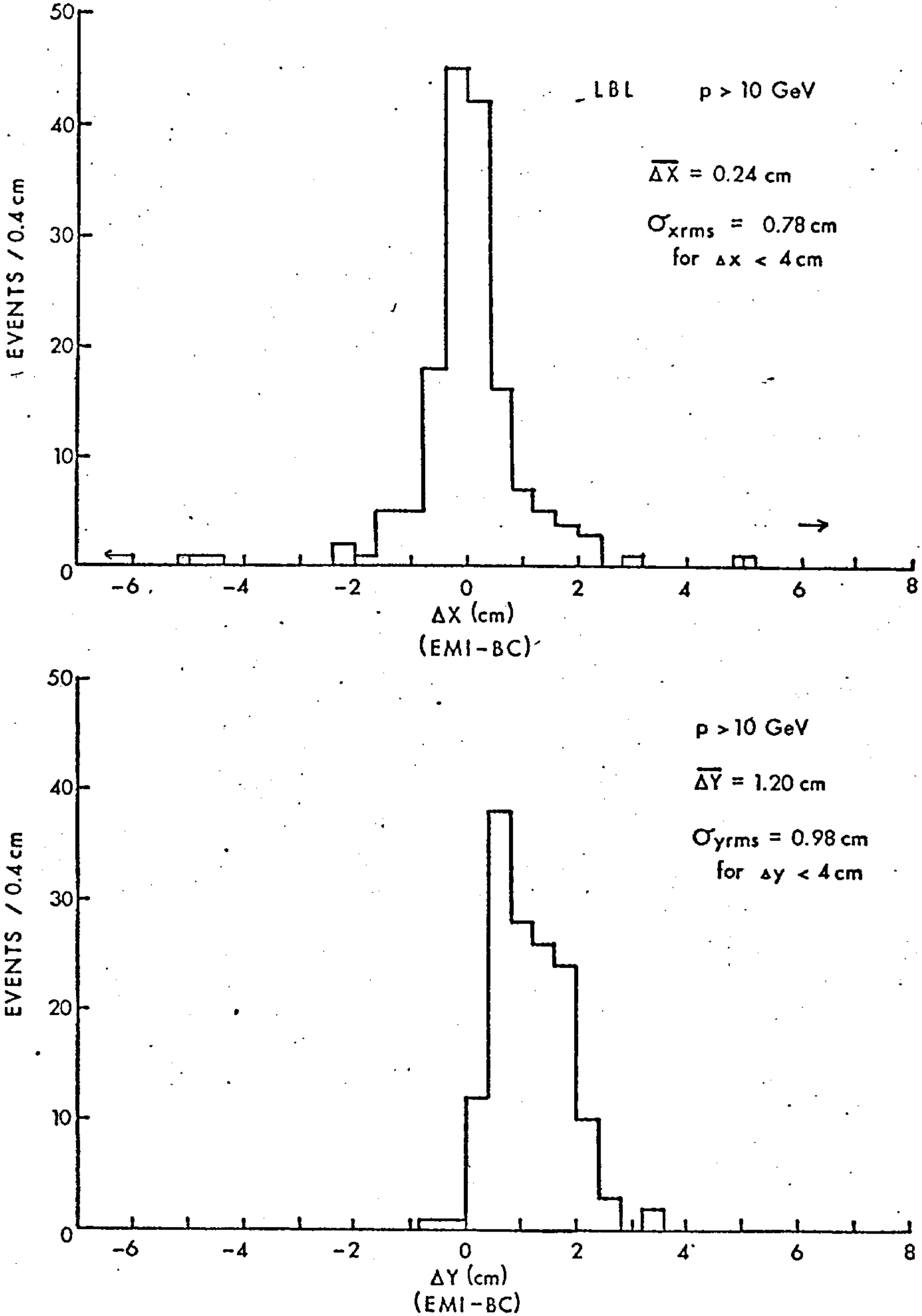
PION ABSORPTION LENGTHS OF ABSORBER TRAVERSED BY MUONS

Fig. 16



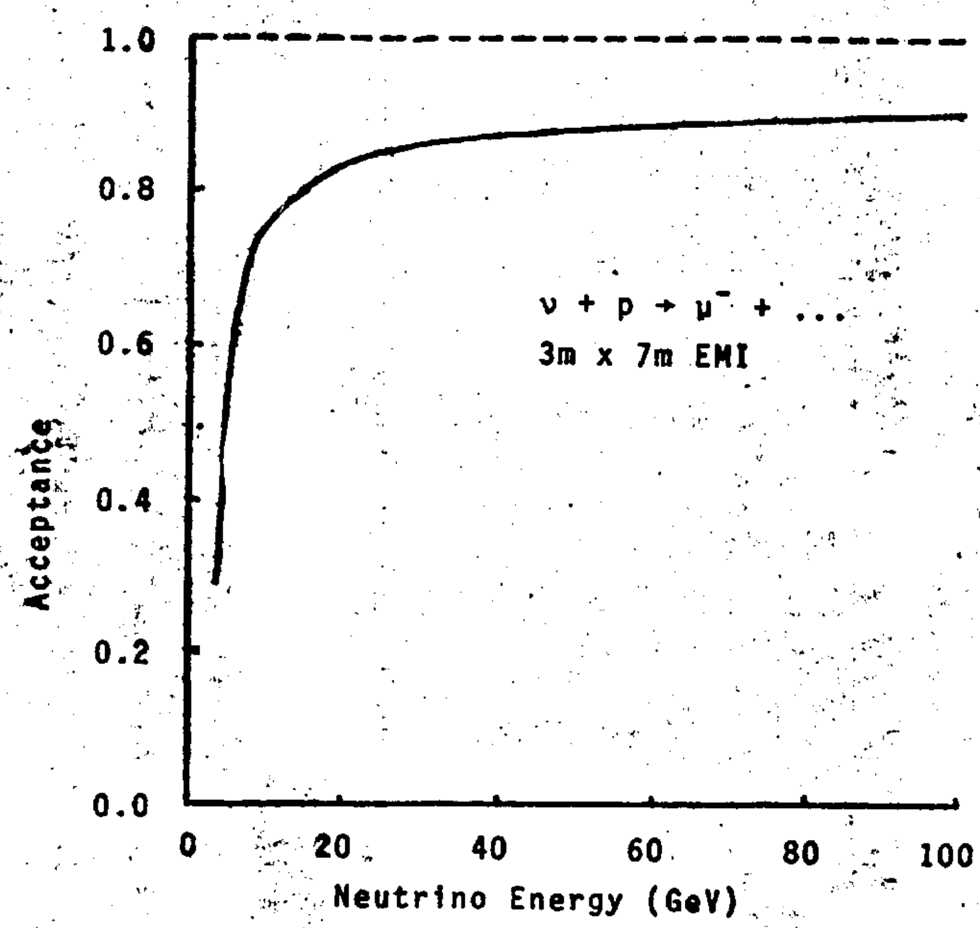
PION ABSORPTION LENGTHS OF ABSORBER TRAVERSED BY HADRONS

Fig. 17



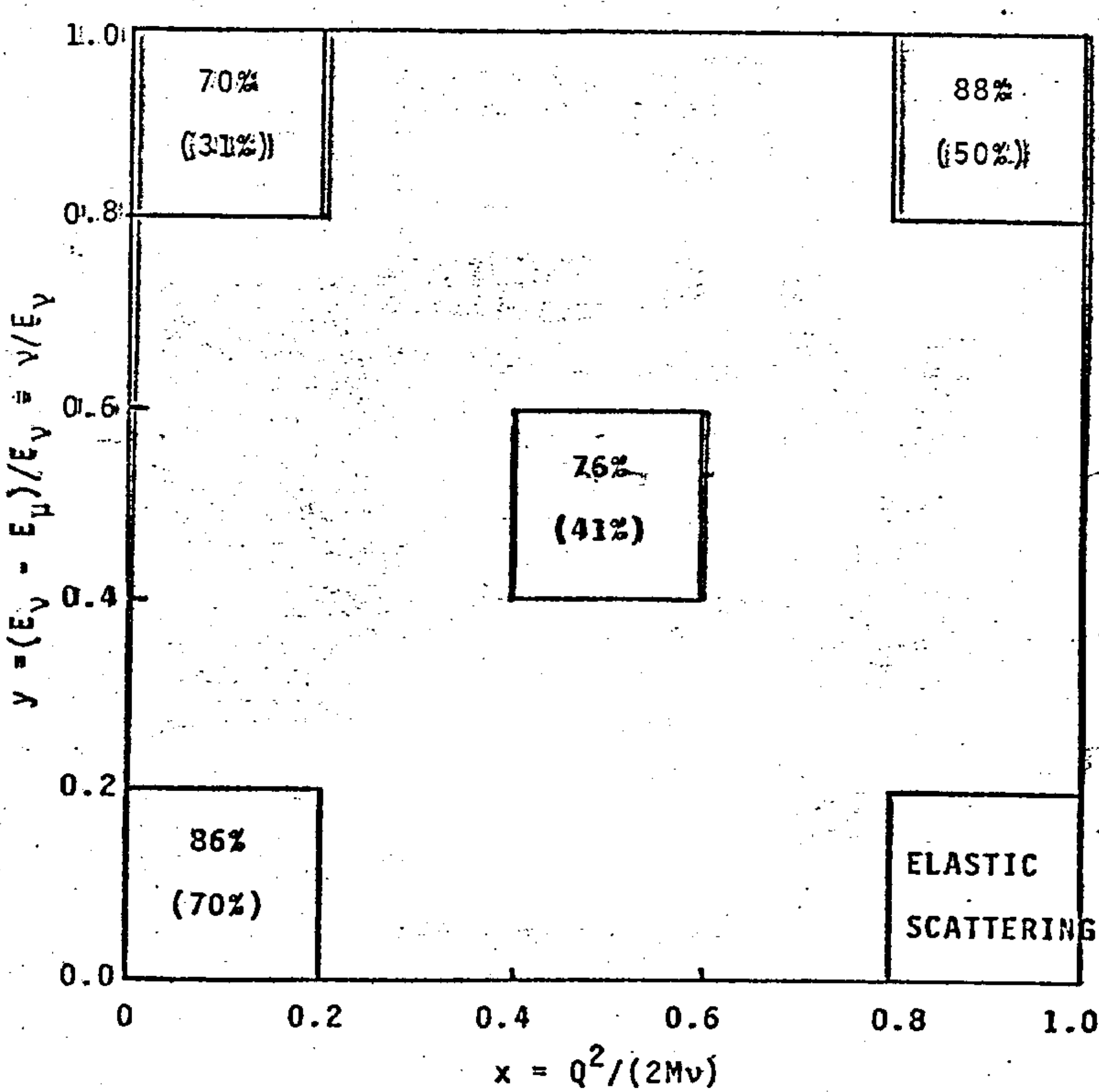
LBL
p > 10 GeV
$\overline{\Delta X}$ = 0.24 cm
σ_{xrms} = 0.78 cm
for Δx < 4 cm
EVENTS / 0.4 cm
ΔX (cm)
(EMI-BC)
p > 10 GeV
$\overline{\Delta Y}$ = 1.20 cm
σ_{yrms} = 0.98 cm
for Δy < 4 cm
EVENTS / 0.4 cm
ΔY (cm)
(EMI-BC)

Fig. 18



EMI GEOMETRICAL ACCEPTANCE

Fig. 19



DETECTION EFFICIENCY FOR NEUTRAL CURRENT EVENTS
WITH 30% NEON IN 15'-BUBBLE CHAMBER
(Numbers in parenthesis refer to bare bubble chamber)

Fig. 20

The table below shows the distribution of the remaining 22 events. In parentheses is the number of events for which a muon was indicated by the EMI.

$\Sigma\vec{p}$ (GeV/c) / prongs	<1	1-3	3-10	10-30	30-100	>100	
3	3	4	5	1	1(1)		14(1)
5			1	1(1)	2(1)		4(2)
7				2(2)	1(1)		3(3)
9							
11					1		1
	3	4	6	4(3)	5 (3)	0	22(6)

None of the 13 events below 10 GeV/c had an identified muon whereas 6 of the 9 above 10 GeV did have an identified muon. The properties of the six events for which the muon was seen are as follows:

Roll	Frame	Prongs	$/\Sigma\vec{p}/$	P_μ	Hits
21	326	7	28.5	12.5	6
21	8692	3	56	53	1
21	8801	7	42	4.0	4
21	9248	5	33	28.6	2
22	5537	5	23.2	17.3	4
22	5624	7	25.8	12.6	6

where "Hits" means the number of tracks that extrapolate out to hit one of the EMI counters. In each of these events the highest momentum negative track extrapolated out to within 1.5 cm of a point where a track was detected in the EMI. No other track in any of these events extrapolated to closer than 7 cm from a point where a track was detected

$\bar{\nu}$ Run in Fermilab 15' B.C.

Total Film so far 26,000 pictures
Approved 200,000 "
This paper 7,000 "

ANL - CMU ½ : ½

Selection: 1) ≥ 8 GeV/c Visible Energy.
2) No wall events.

Caution! Data very preliminary.
1) Not double scanned.
2) Some event topologies ∴ Wall.
3) No understanding of neutron B.G.

Find: 1) (0.93 ± 0.12) events / 100 frames
2) 48% ≥ 1 fast forward +ve.
3) 17% ≥ 1 " " −ve.
4) 32% ≥ 1 " " +ve and −ve
5) 3% no " " (≥ 2 GeV/c)

ν Contamination $\sim \frac{17}{17+48} \sim .26$
6) ~ .26 γ / event.
7) .16 ± .05 V/event.

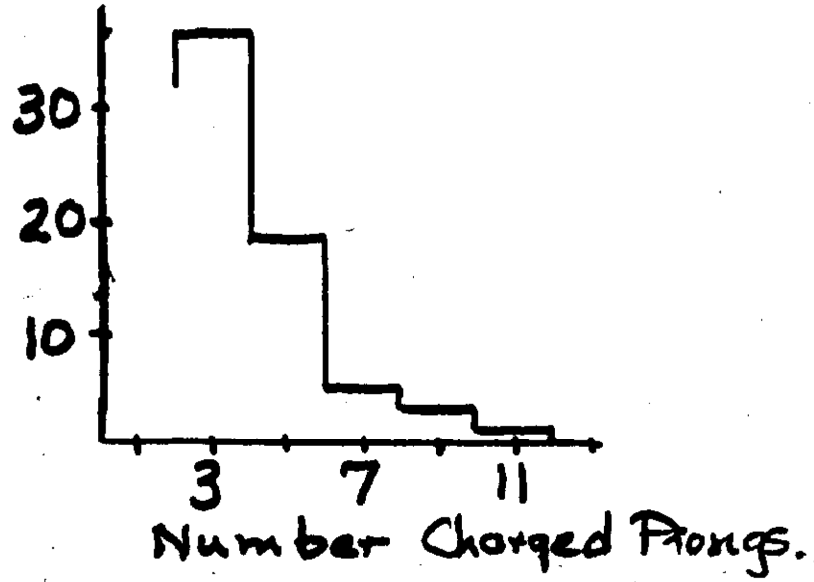


Fig. 22